

Exciting Baryons with MAMI

Michael Ostrick

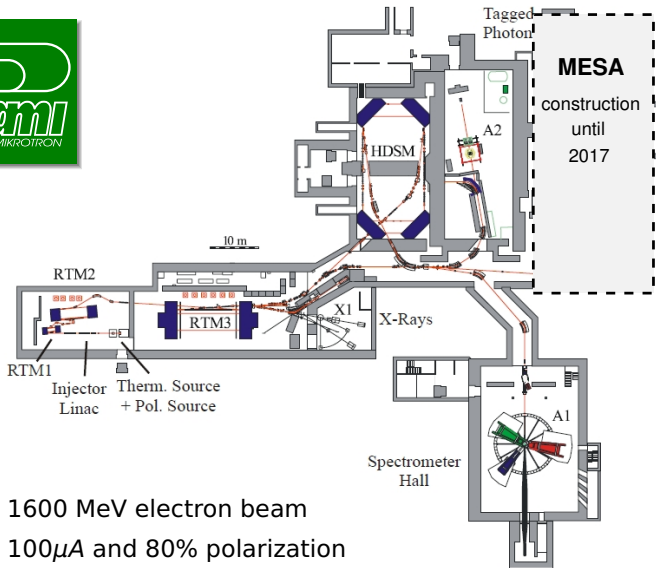
Institut für Kernphysik
Johannes Gutenberg-Universität Mainz, Germany

A2 Collaboration



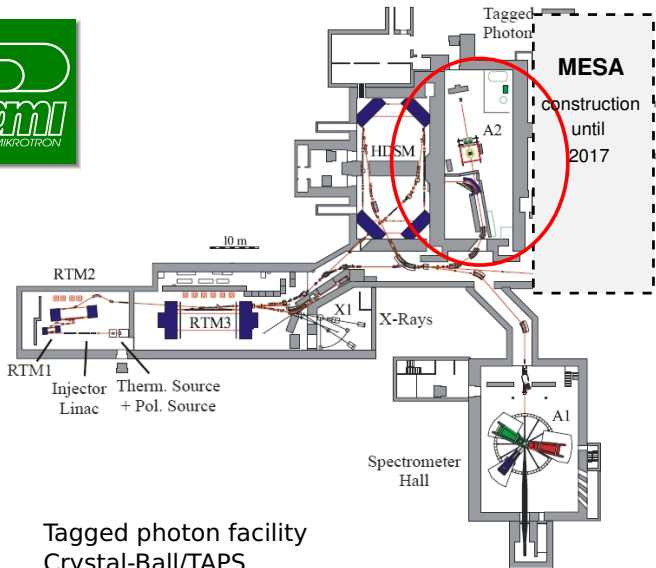
- Instrumentation and Motivation
- Recent Results:
 - $\gamma N \rightarrow \pi N$
 - $\gamma p \rightarrow \eta p$
 - $\gamma p \rightarrow \eta' p$
- Summary and Outlook

The Mainz Microtron MAMI



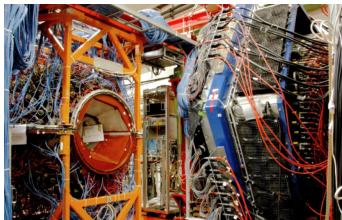
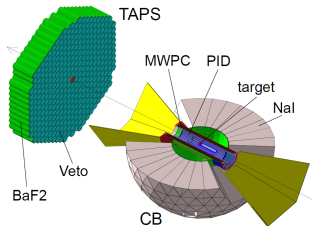
- 180 - 1600 MeV electron beam
- up to $100\mu\text{A}$ and 80% polarization
- $\delta E \sim 100 \text{ KeV}$

A2-Experiment at MAMI



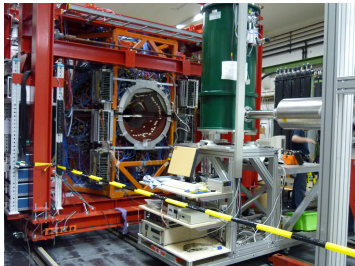
Tagged photon facility
Crystal-Ball/TAPS

The Crystal Ball at MAMI



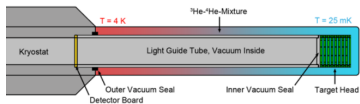
- **Crystal Ball:**
 $672 \text{ NaI}, 20^\circ < \theta < 160^\circ$
- **TAPS:**
 $366 \text{ BaF}_2 + 72 \text{ PbWO}_4,$
 $2^\circ < \theta < 20^\circ$
- **PID:** via $\Delta E - E$,
plastic scintillator barrel
- **charged particle tracking:**
MWPC, no B-field
- **Trigger:**
energy deposit in CB,
clusters of energy deposit

Polarized targets for Crystal Ball at MAMI



- Frozen spin technique
- Material: buthanol (>80%), D-buthanol(>70%)
- $T = 20\text{mK}$; 2000h relaxation time
- holding coils for transverse and longitudinal spin orientation

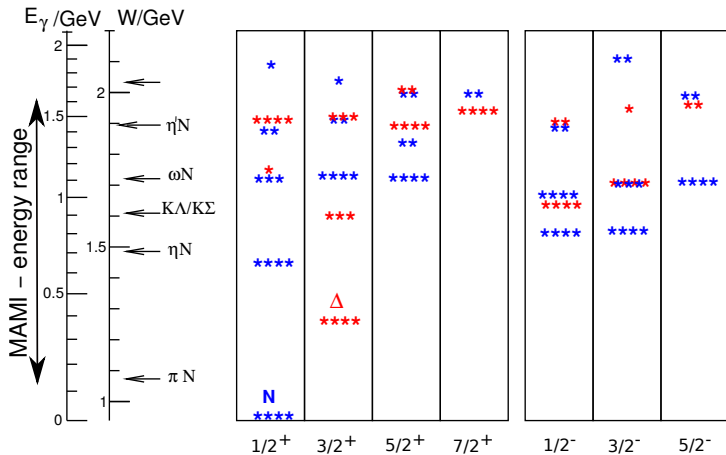
New 2015: active polarized target



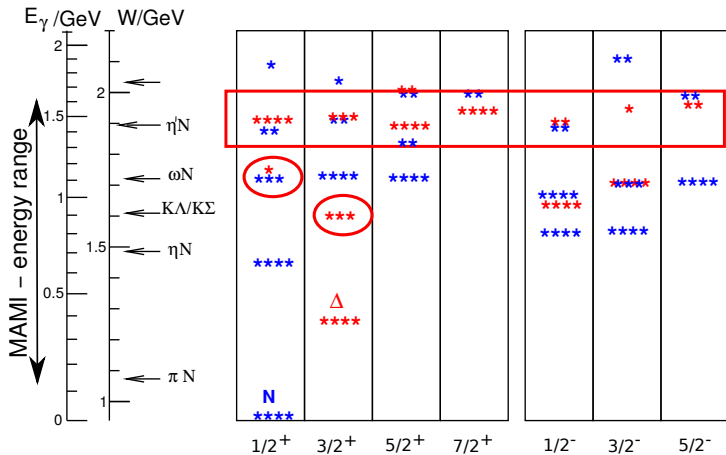
polarizable scintillator
70% polarization
@ 200mK and 2.5 T



Exciting Baryons with MAMI

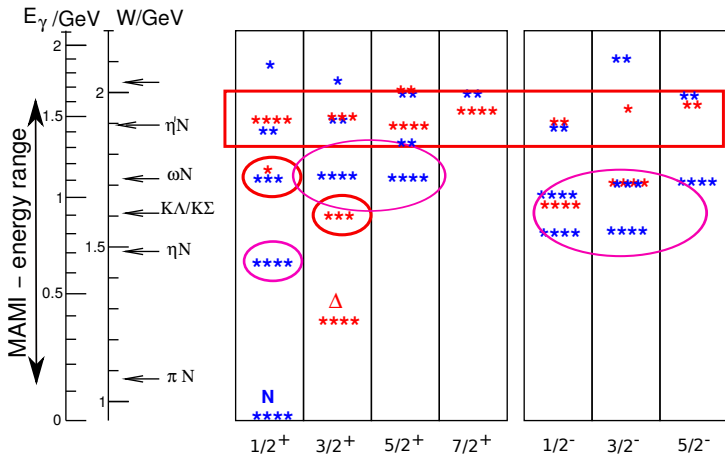


Exciting Baryons with MAMI



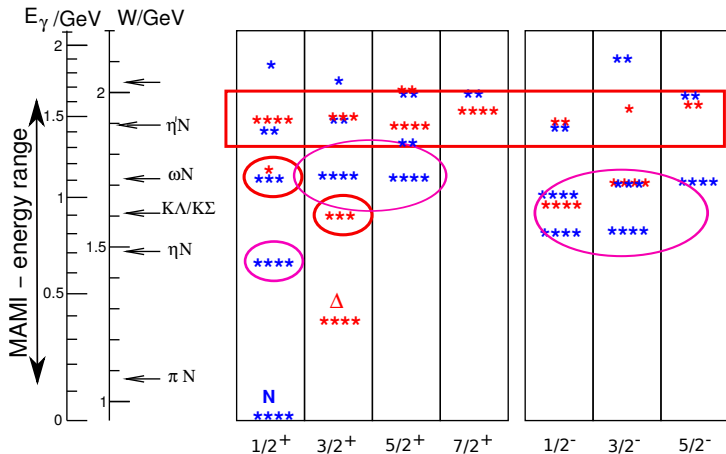
- Several states below 2 GeV need confirmation

Exciting Baryons with MAMI



- Several states below 2 GeV need confirmation
- Pole positions and couplings need to be constrained

Exciting Baryons with MAMI



- Several states below 2 GeV need confirmation
- Pole positions and couplings need to be constrained
- Background, thresholds and coupled channel dynamics

Spin Observables in pseudo-scalar meson photoproduction

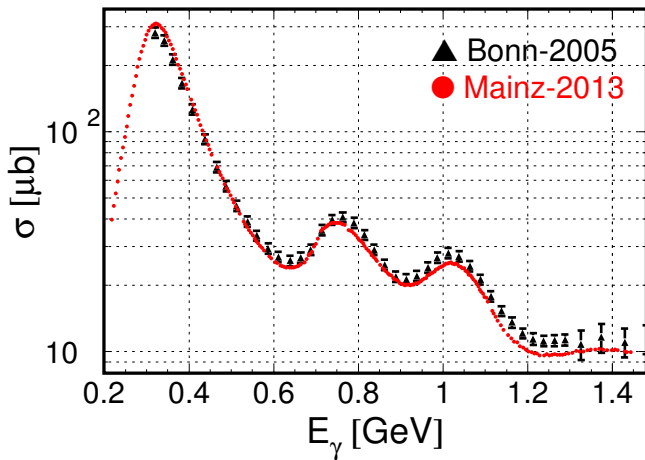
With polarized beam and target

beam polarization		target polarization		
		x	y	z
unpolarized	σ_0	-	T	-
linear	Σ	H	-P	G
circular	-	F	-	E

$$\frac{d\sigma}{d\Omega} = \sigma_0 \left[1 - P_\gamma^{lin} \Sigma \cos 2\phi \right. \\ \left. + P_T^x (P_\gamma^\circ F - P_\gamma^{lin} H \sin 2\phi) + P_T^y (T - P_\gamma^{lin} P \cos 2\phi) \right. \\ \left. + P_T^z (P_\gamma^{lin} G \sin 2\phi - P_\gamma^\circ E) \right]$$

→ Farah Afzal's talk (Parallel-A)

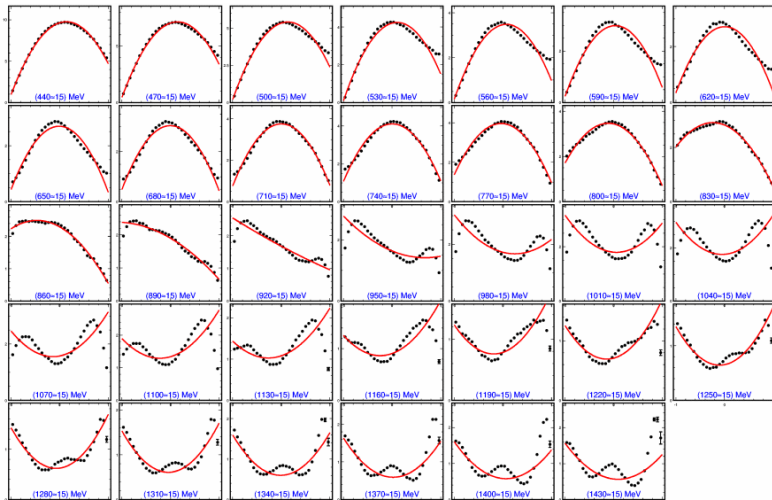
$\gamma p \rightarrow \pi^0 p$ - cross section



30 angular bins for each 4 MeV energy bin

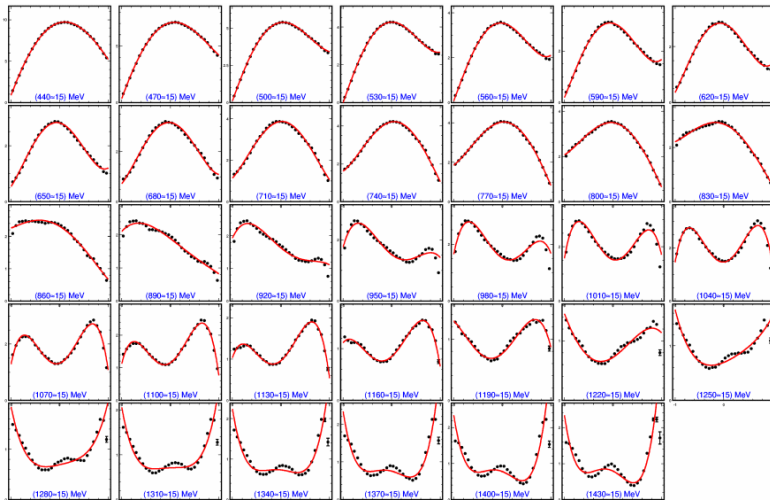
$\gamma p \rightarrow \pi^0 p$ - cross section

$$\frac{d\sigma}{d\Omega} = \sum_{k=0}^{2l_{max}} A_{\sigma}^k(W) P_k(\cos\theta); \quad l_{max} = 1$$



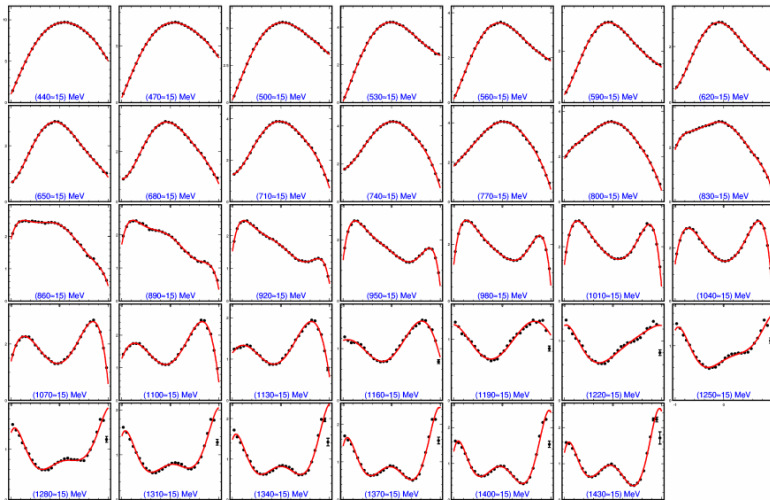
$\gamma\rho \rightarrow \pi^0\rho$ - cross section

$$\frac{d\sigma}{d\Omega} = \sum_{k=0}^{2l_{max}} A_{\sigma}^k(W) P_k(\cos\theta); \quad l_{max} = 2$$



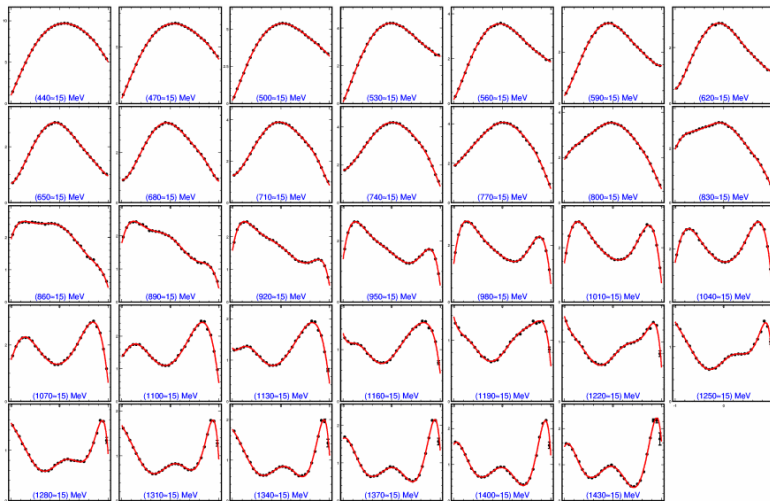
$\gamma\rho \rightarrow \pi^0\rho$ - cross section

$$\frac{d\sigma}{d\Omega} = \sum_{k=0}^{2l_{max}} A_{\sigma}^k(W) P_k(\cos\theta); \quad l_{max} = 3$$



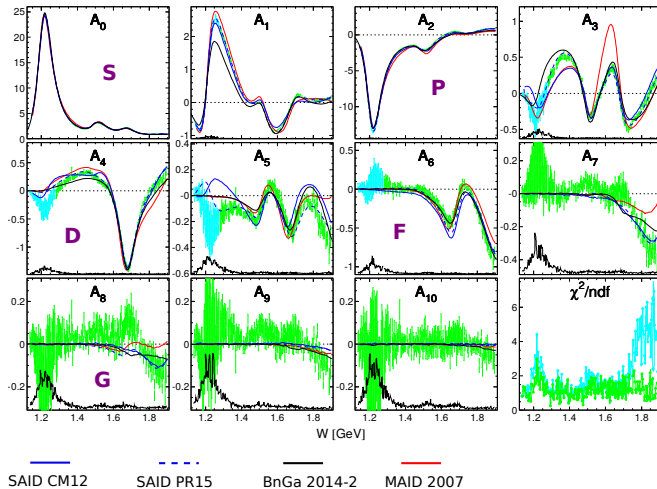
$\gamma p \rightarrow \pi^0 p$ - cross section

$$\frac{d\sigma}{d\Omega} = \sum_{k=0}^{2l_{\max}} A_{\sigma}^k(W) P_k(\cos\theta); \quad l_{\max} = 4$$



$\gamma p \rightarrow \pi^0 p$ - cross section

Legendre coefficients:

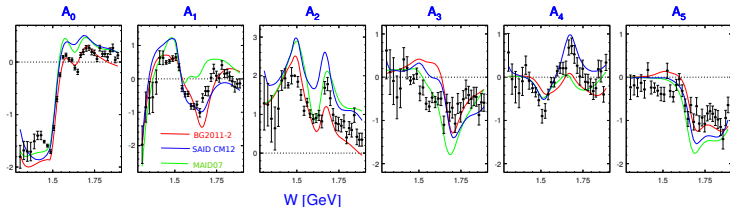


$\gamma p \rightarrow \pi^0 p$: transverse spin dependence

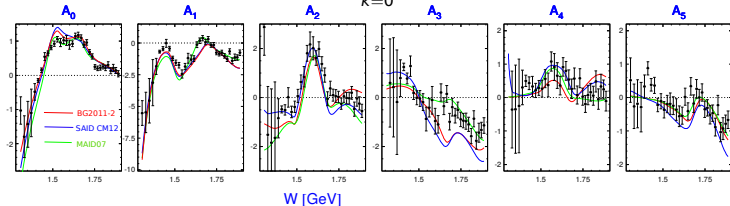
beam polarization		target polarization		
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unpolarized	σ_0	-	T	-
linear	Σ	H	-P	G
circular	-	F	-	E

$\gamma p \rightarrow \pi^0 p$: transverse spin dependence

$$T \cdot \frac{d\sigma_0}{d\Omega} = \sin \theta \sum_{k=0}^{2l_{\max}-1} A_T^k(W) P_k(\cos \theta)$$



$$F \cdot \frac{d\sigma_0}{d\Omega} = \sin \theta \sum_{k=0}^{2l_{\max}-1} A_F^k(W) P_k(\cos \theta)$$



Single energy partial wave analysis

Legendre coefficients for each observable O
depend quadratically on multipoles: $M_{\ell,k}(W) : E_{\ell\pm}, M_{\ell\pm}$

$$A_j^O(W) \sim \sum_{\ell,\ell',k,k'} M_{\ell,k}(W) M_{\ell',k'}^*(W)$$

→ coupled quadratic equations

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- Discrete ambiguities
→ at least 5 observables (Omelaenko '81, Wunderlich 2014)
- Exp. acceptance and uncertainties → ambiguities

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- Discrete ambiguities
→ at least 5 observables (Omelaenko '81, Wunderlich 2014)
- Exp. acceptance and uncertainties → ambiguities
- **Below 2π threshold:**
unitarity (Fermi-Watson theorem) constrains phases

$\gamma p \rightarrow \pi^0 p$: threshold ($E_\gamma < 190$ MeV)

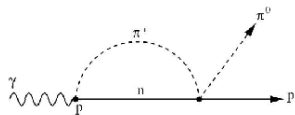
→ talk by Stefan Scherer (Plenary 26-1)

Unitarity:

P-waves are real: $\text{Im}M_{1+} \sim \text{Im}M_{1-} \sim \text{Im}E_{1+} \sim 0$

$$\text{Im}E_{0+} = \beta(E_\gamma) \frac{q_{\pi^+}}{m_{\pi^+}};$$

$$\beta(E_\gamma^{\text{thr}}) = (3.35 \pm 0.08) \cdot 10^{-3} / m_{\pi^+}$$



$$\beta = E_{0+}(\gamma p \rightarrow \pi^+ n) \cdot a(\pi^+ n \rightarrow \pi^0 p)$$

$\gamma p \rightarrow \pi^0 p$: threshold ($E_\gamma < 190$ MeV)

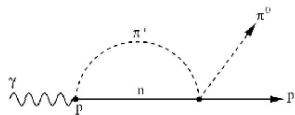
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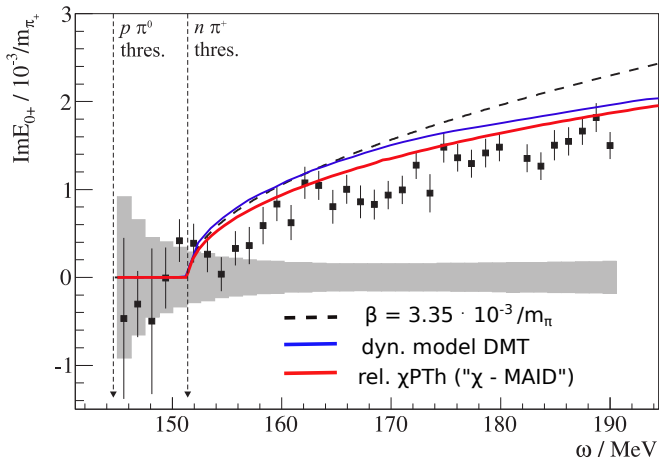
$$\beta = E_{0+}(\gamma p \rightarrow \pi^+ n) \cdot a(\pi^+ n \rightarrow \pi^0 p)$$

Experiment:

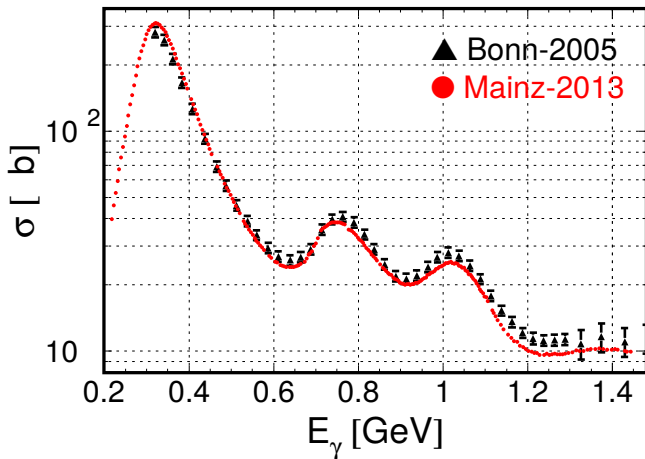
- Measurements of $d\sigma/d\Omega$ and Σ determine all real parts ($\text{Re}E_{0+}$, $\text{Re}M_{1+}$, $\text{Re}M_{1-}$, $\text{Re}E_{1+}$)
→ PRL111 (2013) 062004
- Transverse target polarisation $T \rightarrow \text{Im}E_{0+}$

$$T \cdot \frac{d\sigma}{d\Omega} \sim \text{Im} [E_{0+}^* (E_{1+} - M_{1+})]$$

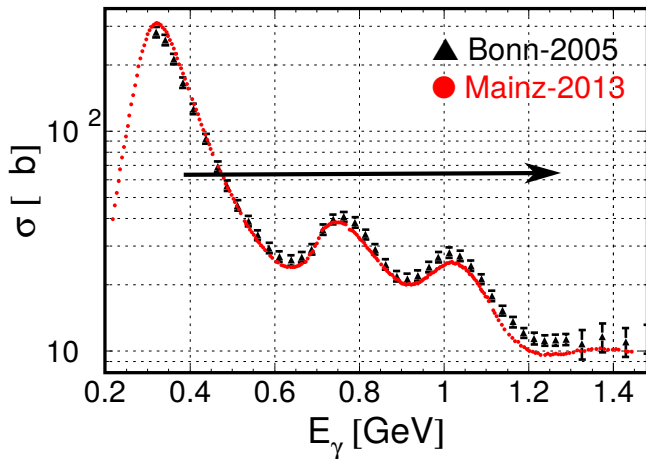
$\gamma p \rightarrow \pi^0 p$: threshold ($E_\gamma < 190$ MeV)



$\gamma p \rightarrow \pi^0 p$: Single energy partial wave analysis



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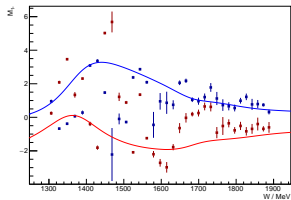
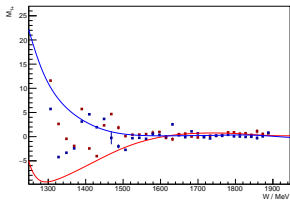
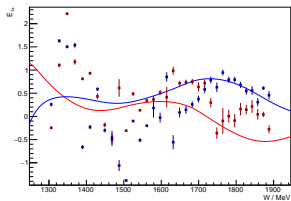
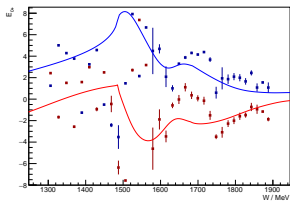


$\gamma p \rightarrow \pi^0 p$: Single energy partial wave analysis

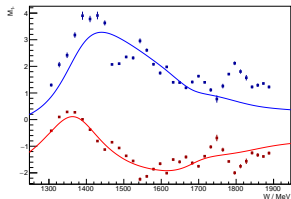
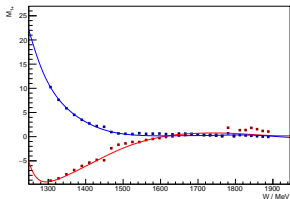
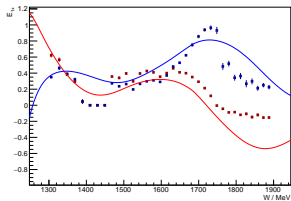
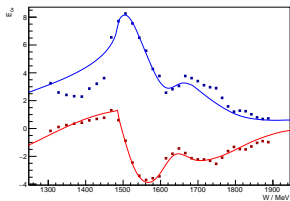
beam polarization		target polarization		
		x	y	z
unpolarized	σ_0	-	T	-
linear	Σ	H	-P	G
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- Use available "modern" data from ESLA and MAMI
- Fit all s-, p-, d- and f-wave multipoles: 24 parameters
- Constrain higher multipoles to a model, e.g. BnGa2014-2

$\gamma\rho \rightarrow \pi^0\rho$: Single energy partial wave analysis

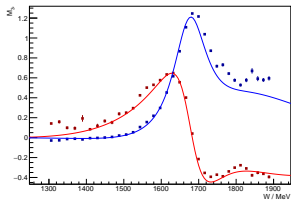
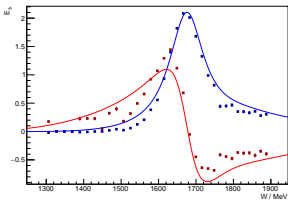
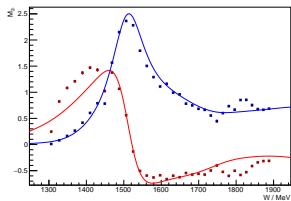
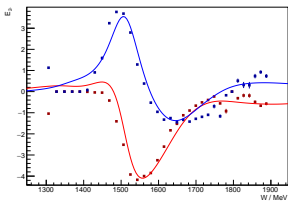


$\gamma\rho \rightarrow \pi^0\rho$: Single energy partial wave analysis



Phases of multipoles fixed to BnGa2014-2 solution

$\gamma\rho \rightarrow \pi^0\rho$: Single energy partial wave analysis



Phases of multipoles fixed to BnGa2014-2 solution

$\gamma\rho \rightarrow \pi^0\rho$: Single energy partial wave analysis

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$\gamma p \rightarrow \pi^0 p$: Single energy partial wave analysis

beam polarization		target polarization		
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circular	-	F	-	E

- Use available "modern" data from ESLA and MAMI
- Fit all s-, p-, d- and f-wave multipoles: 24 parameters
- Constrain higher multipoles to a model, e.g. BnGa2014-2
- Realistic solutions with additional (phase-)constraints to models
- Goal: implement constraints from fixed-t analyticity

Isospin separation

- 3 Isospin amplitudes: $A^{3/2}$, $A_p^{1/2}$, $A_n^{1/2}$

$$A_{\gamma p \rightarrow p \pi^0} = A_p^{1/2} + 2/3 A^{3/2}$$

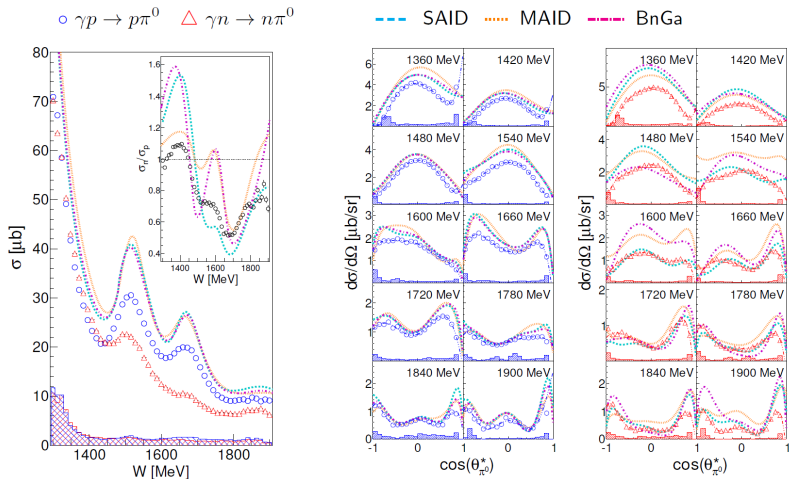
$$A_{\gamma p \rightarrow n \pi^+} = \sqrt{2} (A_p^{1/2} - 1/3 A^{3/2})$$

$$A_{\gamma n \rightarrow n \pi^0} = \sqrt{2} (-A_n^{1/2} + 2/3 A^{3/2})$$

- $\gamma p \rightarrow \pi^+ n$
- Dedicated neutron program (LD_2 , ${}^3\text{He}$, pol. *D*-butanol)
 $\gamma n \rightarrow \pi^0 n$ and $\gamma n \rightarrow \eta n$

→ Manuel Dieterle's talk (Parallel-A 26-2)

$\gamma D \rightarrow \pi^0 n p$



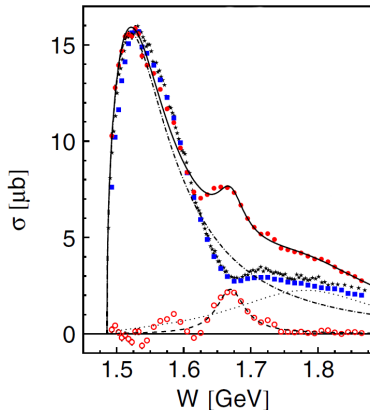
Photoproduction of η mesons

Photoproduction of η mesons

★ $\gamma p \rightarrow \eta p$

■ $\gamma D \rightarrow \eta p$ (n)

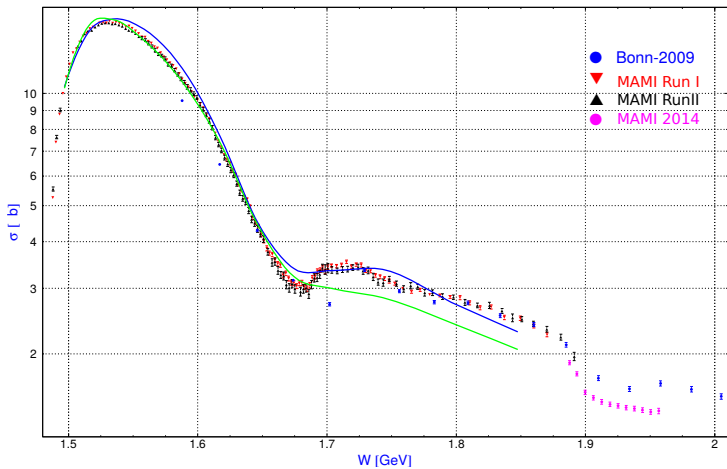
● $\gamma D \rightarrow \eta n$ (p)



- Resonance dominated
- Large E_{0+} amplitude:
 - $N(1535)S_{11}$
 - $N(1650)S_{11}$
 - $N(1895)S_{11}$
- "bump-dip" structure at 1670 MeV:
 - $N(1535)$ - $N(1650)$ interference ?
 - Coupled channel dynamics ($K\Lambda$, $K\Sigma$ thresholds)

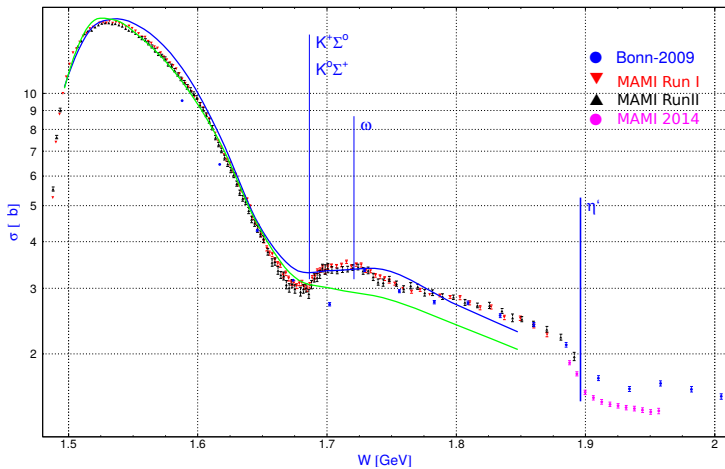
$\gamma p \rightarrow \eta p$: cross section

new data from 2014 included:



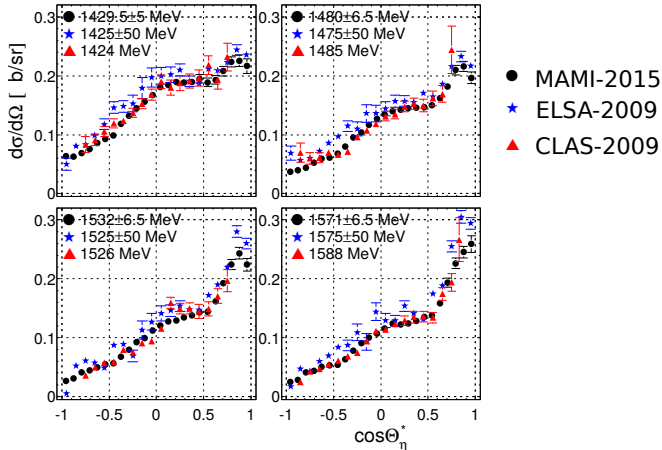
$\gamma p \rightarrow \eta p$: cross section

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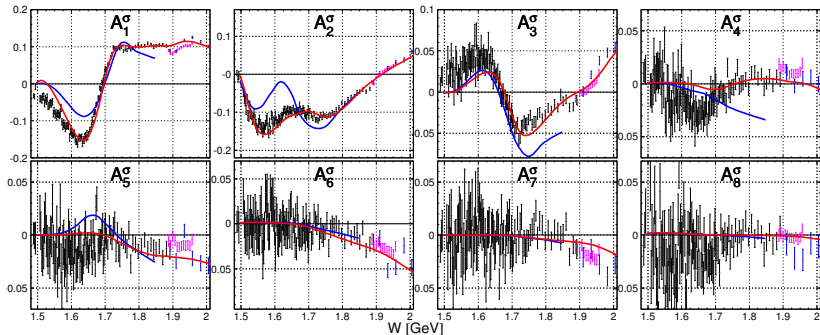
$\gamma p \rightarrow \eta p$: differential cross section

new data from 2014 included



$\gamma p \rightarrow \eta p$: cross section

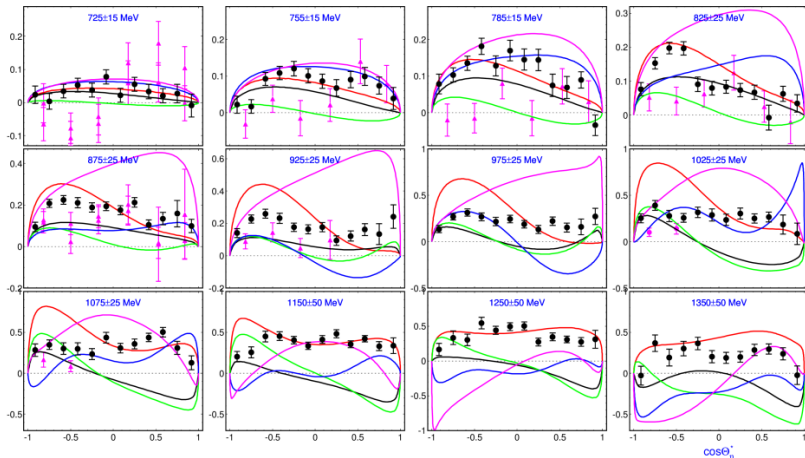
$$\frac{d\sigma_0}{d\Omega} = \sum_{k=0}^{j_{\max}} A_k^\sigma(W) P_k(\cos\theta)$$



— η -MAID (2003)

— η -MAID refit (2015) including all N^* states.

$\gamma\bar{p} \rightarrow \eta p$: target asymmetry T



black circles – MAMI-2014
(PRL 113, 102001, 2014)

magenta triangles: Bonn data
(PRL 81, 534, 1998)

red line: η MAID-03 (NP A700, 429, 2002)

blue: SAID GE09 (PRC 82, 035208, 2010)

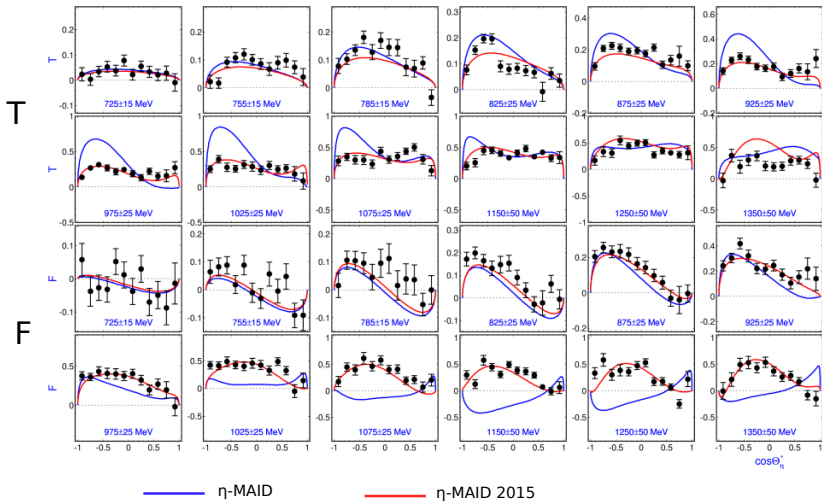
green: BG2011-02 (EPJA 47, 153, 2011)

black: Giessen Model (PRC 87, 015201, (2013)

magenta: Tr^2 (EPJA 50, 120, 2014)

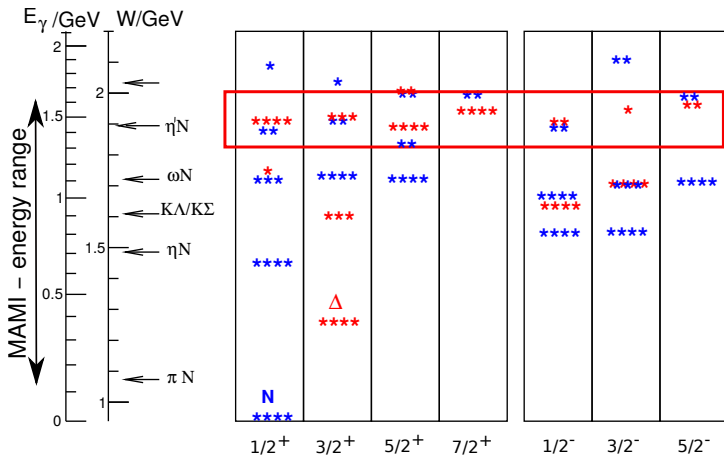
$\gamma\vec{p} \rightarrow \eta p$: η -MAID2015

Refit of η -MAID03 (V.Kashevarov, L.Tiator)



$\gamma\vec{p} \rightarrow \eta p$: η -MAID2015

Refit of η -MAID03 (V.Kashevarov, L.Tiator)



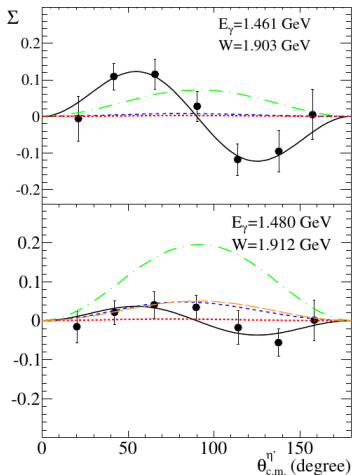
Photoproduction of η' mesons

Photoproduction of η' mesons

- Dynamics not well understood
 S_{11} and P_{11} resonances
+ vectormeson exchange
- Models:
 - Huang, Haberzettl, Nakayama (PRC87)
 - Chiang et al. (η' -MAID, PRC68)
 - Zhong, Zhao (PRC84)
 - Tryasuchev (Phys.At.Nucl.76)

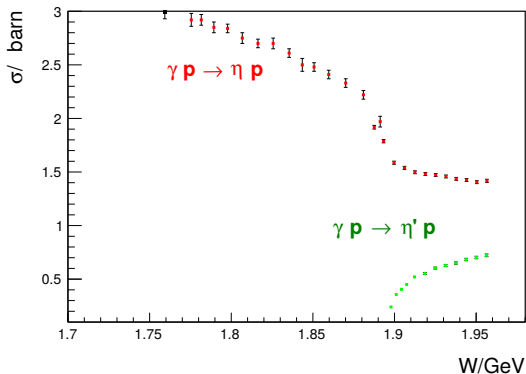
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 - Tryasuchev (Phys.At.Nucl.76)
- Photon asymmetry Σ
from GRAAL (arXiv:1407.6991)
 N^* beyond S- and P-waves?

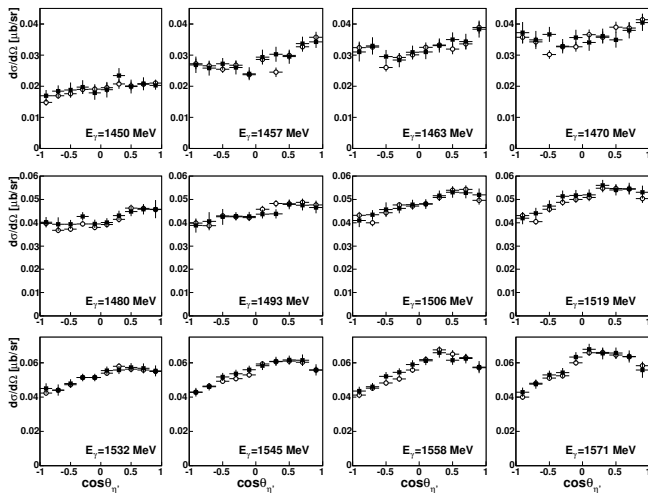


Photoproduction of η' mesons

Total cross section from new MAMI data (2014):



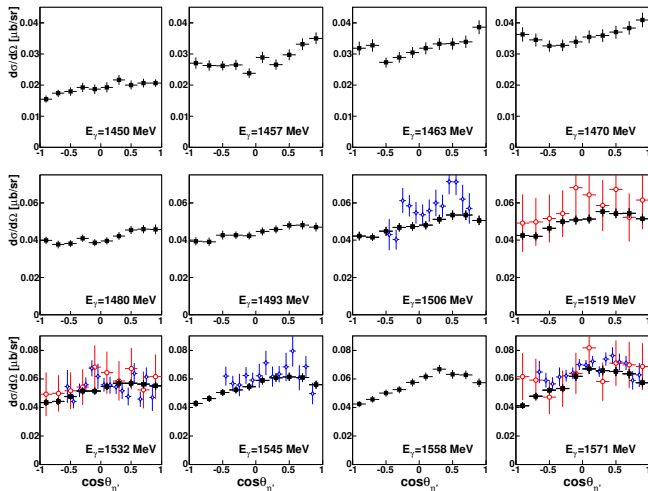
Photoproduction of η' mesons



■ $\eta' \rightarrow 2\gamma$

○ $\eta' \rightarrow \eta\pi^0\pi^0 \rightarrow 6\gamma$

Photoproduction of η' mesons



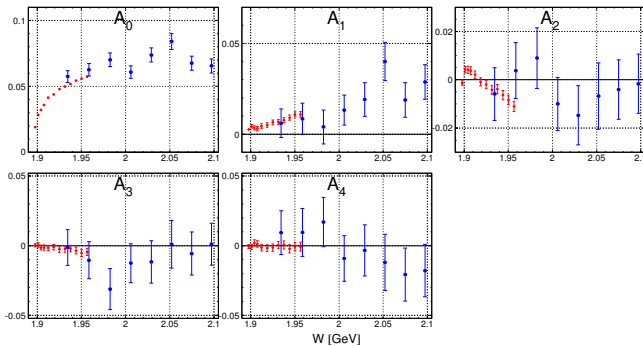
MAMI

CLAS

CB-ELSA

Photoproduction of η' mesons

Legendre expansion:



Summary and Outlook

- Precise new data from MAMI
→ partial wave structure of meson photoproduction
- Single energy PWA with analytical constraints
- Results for:

$$\vec{\gamma}\vec{N} \rightarrow \pi N$$

$$\vec{\gamma}\vec{N} \rightarrow \eta N$$

$$\gamma p \rightarrow \eta' p$$

in parallel: $\pi\pi N$, $\pi\eta N$, ωN

Summary and Outlook

- Precise new data from MAMI
→ partial wave structure of meson photoproduction
- Single energy PWA with analytical constraints
- Results for:

$$\gamma\vec{N} \rightarrow \pi N$$

$$\gamma\vec{N} \rightarrow \eta N$$

$$\gamma p \rightarrow \eta' p$$

in parallel: $\pi\pi N$, $\pi\eta N$, ωN

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